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Investigation of the Vehicle Mobility in Fording

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This contribution concerns a general purpose fluid-multibody system (MBS) simulation framework that can be used to analyze the fluid-solid, two-way coupled dynamics at low to medium Reynolds numbers ($0 < Re < 1500$). The simulation framework can be leveraged to investigate MBS applications that include (*i*) rigid and flexible bodies of arbitrary geometry; (*ii*) bilateral constraints (joints); (*iii*) unilateral constraints associated with impact and contact phenomena; and (*iv*) friction/cohesion.

The fluid dynamics problem is formulated using the fluid momentum and continuity, i.e., Navier-Stokes equations. These equations are spatially discretized via a weakly compressible smoothed particle hydrodynamics (SPH) Lagrangian method [1], which relies on moving markers to store state information associated with fluid phase. The space dependent variables, such as velocity and pressure, are smoothed out locally via a scalar function. That is, to obtain a variable, a gradient, or a hydrodynamics force at an arbitrary location of the domain, one needs to account for partial contributions coming from nearby markers. External forces such as fluid-solid interaction (FSI) force are added to the hydrodynamics force. The fluid equations of motion, which upon spatial discretization become a set of ordinary differential equations, are solved explicitly using a second order Runge-Kutta integration method.

Of several approaches that have been considered in the literature to model the fluid-solid coupling, we show that using a point-cloud discretization of a solid results in an accurate calculation of the fluid-solid coupling forces [2]. In this approach, the MBS dynamics is solved by providing the solver with distributed forces captured by the point cloud representation. Alternatively, a constraint-based approach was examined where the non-penetration conditions were treated as unilateral constraints on fluid markers. In the latter approach, the rigid body forces were not marker resolution independent.

The solution strategy outlined has been implemented in Chrono as a dedicated add-on called Chrono::FSI [3]. Figure 1 shows a vehicle model used in a fording simulation along with its point cloud representation. The refinement of the point cloud can be based on the accuracy required in the fluid system. The vehicle is modeled in Chrono::Vehicle, which is a Chrono toolkit that provides a template based approach to rapid vehicle prototyping. In Chrono::Vehicle, templates define the basic modeling elements (bodies, joints, force elements), impose the subsystem topology, prescribe the design parameters, and implement the common functionality for a given type of subsystem (e.g. suspension) particular to a specific template (e.g. double wishbone).

A heterogeneous parallel computing approach is adopted to speed up the simulation. The state of the fluid system is stored and updated on a graphics processing unit (GPU), while the MBS dynamics solution relies on a shared-memory, multi-core implementation. The efficiency gains obtained by adopting a heterogeneous computing approach can be hindered by the massive data transfer between the GPU and host, which takes place via a relatively high latency, low bandwidth, PCIe bus. We circumvent this issue by minimizing the data transfer to and from the GPU. To this end, the point cloud data for each rigid body resides in the GPU memory. After calculating the distributed forces on the point cloud, those forces are reduced in parallel using the thrust library [4]. The resulting forces and torques (six variables per rigid body), are transferred to the MBS. Similarly, after updating the MBS, the GPU updates the locations and velocities of the points of the cloud, relying on the new position, orientation, velocity, and angular velocity of the rigid objects.

Chrono::FSI has been used for vehicle mobility in fording operations as shown in Figure 2. The computational time per simulation time step is almost entirely dictated by the fluid component and is similar to that of a simulation of a pure fluid system of the same size. This indicates that the minimal data transfer between the GPU and the host system does not slow down the simulation. Finally, it is worth mentioning that Chrono::FSI allows for the simulation of a broad class of fluid-MBS interaction problems that, beyond the fording analysis discussed, concern the general purpose dynamics of rigid and/or flexible bodies interacting with fluid.

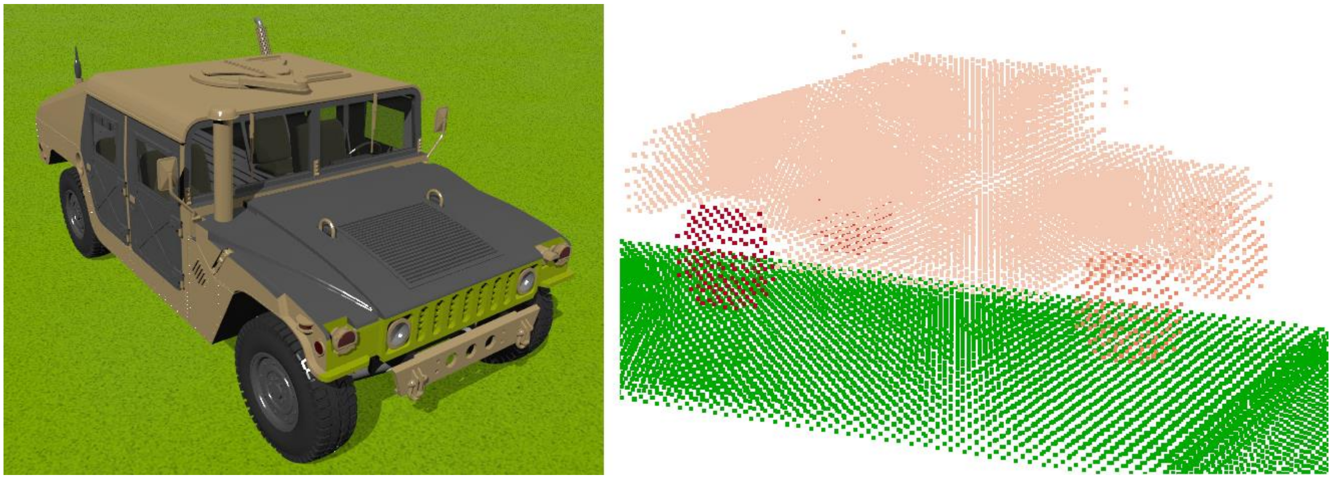

Fig. 1: The vehicle model used in a fording simulation. Any component that interacts with the fluid, such as the vehicle, tire geometries, and the solid boundaries shown in the left image, are represented as a point cloud in the fluid system. The resolution of the point cloud discretization can be changed based on the accuracy or the specific dynamics required.

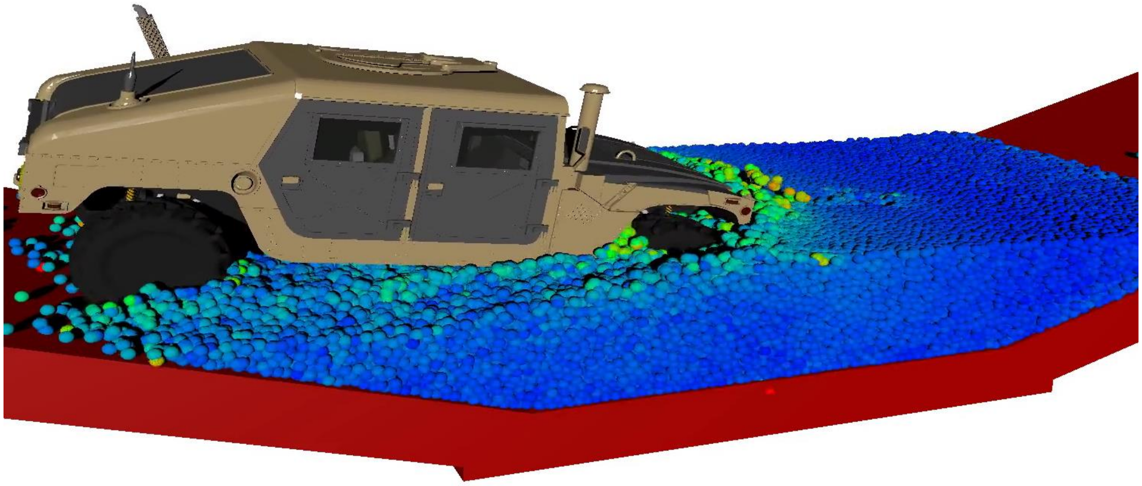

Fig. 2: Simulation of the vehicle mobility in fording using Chrono::FSI

References

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